CDFNOTE 8226

Evidence of Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

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We present evidence for 3 exclusive $\gamma\gamma$ production events wit a background of $0.0^{+0.2}_{-0.0}$ events. Each event has an $\gamma\gamma$ pair, both with $E_T > 5$ GeV and $|\eta| < 1$, and nothing else observable in the CDF detector. The measured cross section for these events is $0.14\ ^{+0.14}_{-0.04}\ (stat)\ \pm 0.03\ (sys)$ pb. Such events have been predicted to occur through $gg \rightarrow \gamma\gamma$ via quark loops, while another gluon exchange cancels the color of the interacting gluons, and leaves the (anti)protons in their ground state. The events observed are consistent with $\bar{p}p \rightarrow \bar{p} + \gamma\gamma + p$ with a predicted cross section of 0.04 pb with a factor 3 to 5 theoretical uncertainty.

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I. INTRODUCTION

QCD-mediated exclusive interactions have tremendous potential as a method of observing new physics at the LHC. However, before detailed conclusions can be drawn, theoretical predictions must be compared against experimental observation. There has been no observation of a QCD-mediated exclusive interaction in hadron-hadron collisions since the observation of exclusive $\pi^+\pi^-$ at the ISR [1]. There are many pitfalls in the extrapolation from the ISR to the Tevatron and LHC, so an observation at the Tevatron is critical to the progress of research projects investigating exclusive interactions at the LHC (the FP420 project [2]). Figure 1 shows the leading order diagram for QCD-mediated exclusive $\gamma\gamma$ interactions.

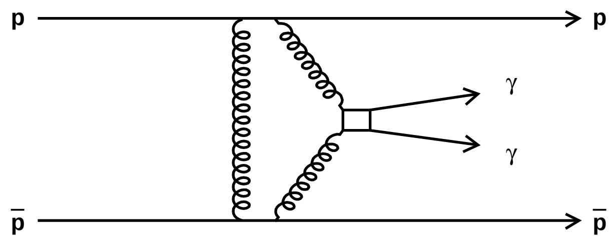

FIG. 1: Leading order diagram for QCD-mediated $\gamma\gamma$ interactions

In March 2001 a Letter of Intent [3] was submitted to the Fermilab Director to add new very forward proton detectors to CDF to search for exclusive production of the Higgs boson, i.e the process $p\bar{p} \to pHp$ and *nothing else*. The observation of the exclusive Higgs process can produce many measurements not available in the inclusive Higgs production processes [4]. The Letter of Intent suggests that exclusive $\gamma\gamma$ production might be possible and, if measurable in CDF could "calibrate" the diverse theoretical predictions.

A. From the Letter of Intent

"Fortunately there is a process that is very closely related to exclusive Higgs production, namely the exclusive production of two photons by gg-fusion through a quark loop. While in the Higgs case only the top quark loop is significant, in this case all quarks contribute. The crucial similarity is that in both cases the final state, H or $\gamma\gamma$, is not strongly interacting. Therefore the non-perturbative parts of the process should be *identical* in exclusive $\gamma\gamma$ and H production. The ratio

$$\frac{d\sigma}{dM_{\gamma\gamma}}(M_{\gamma\gamma}) : \sigma_H(M_H)$$

should be theoretically well predicted (although we cannot measure both at the same Q^2), and related to the inclusive ratio (selecting the gg part of the $\gamma\gamma$ production). A calculation including helicity effects has not yet been done. We can measure $p\bar{p} \to p\gamma\gamma\bar{p}$ as a function of $M(\gamma\gamma)$ and that should give us a reliable estimate of $p\bar{p} \to pH\bar{p}$. [...] This study will be done without attempting to detect the p and $\bar{p}$, so all t and ϕ values are accepted. We are not likely to find any exclusive $\gamma\gamma$ events with the p and $\bar{p}$ detected."

B. Theoretical Developments

The first published theoretical work, by the Durham group [4], is mainly concerned with exclusive Higgs, dijet, $t\bar{t}$ and SUSY particles. About exclusive $\gamma\gamma$ production (in section 3.3) they say:

"At first sight, the subprocess $gg^{PP} \to \gamma\gamma$ appears attractive to serve as an alternative gg^{PP} luminosity monitor for the exclusive double diffractive processes. However it turns out that the event rate is too small." They find $\sigma(30^\circ < \theta^*_\gamma < 150^\circ) \simeq 0.3(0.04)$ pb for $M_{\gamma\gamma} \sim 50(120)$ GeV. They did not give estimates for the lower masses of relevance here.

Later the Durham group made a refined calculation of fully exclusive $\gamma\gamma$ production [5]. They calculated a cross section, dominated by the $gg \to \gamma\gamma$ process, of $\sigma_{\gamma\gamma}(E_T(\gamma) > 5$ GeV, $|\eta(\gamma)| < 1.0) = 0.04$ pb. The probability of events with proton dissociation passing our forward rapidity cuts (especially the BSC) is said to be small, "the admixture of processes with incoming proton dissociation is not expected to exceed 0.1%". They also calculate that the contribution from quark exchange diagrams is $< 5\%$ and from $\gamma\gamma \to \gamma\gamma$ is $< 1\%$. They say "Therefore indeed this process (exclusive $\gamma\gamma$) can be used as a 'standard candle' to check and to monitor the exclusive gg^{PP} luminosity that has been used for the prediction of the Higgs cross section." See also Refs [6] for papers on exclusive processes. There are no other predictions of the fully exclusive process.

II. SIGNAL MC

The Exhume Monte Carlo [7], written by Pilkington and Monk, is based on the Durham calculation. It is the only generator to simulate the exclusive two photon process, and thus is the signal MC used for this analysis.

III. DATA SAMPLE & EVENT SELECTION

This analysis uses an integrated luminosity of 532 ± 32 pb^{-1} of data collected with the CDF detector [8] between December 7 2004 and November 9 2005. It uses a trigger that was specifically designed for this analysis. The trigger requires two electromagnetic clusters in $0 < |\eta| < 3.6$ with online $E_T > 4$ GeV and a veto on activity in the first Beam Shower Counter (BSC-1, $5.4 < |\eta| < 5.9$). Offline event selection can be broken into three categories; 1) photon identification, 2) cosmic rejection, 3) exclusivity

A. Photon Identification

Events containing two photons with offline $E_T > 5$ GeV and $0 < |\eta| < 1.0$ are selected from the triggered data. Photon identification is done using the Had/EM energy ratio of the cluster as well as the lateral shower-maximum shape. The photon is also required to have either 0 or 2 tracks pointing to the calorimeter cluster. If there are 2 tracks pointing to the cluster, then those tracks must be consistent with a conversion pair. Events with tracks (other than conversions) are excluded from the candidate sample. Isolation is not applied in the photon identification stage of the selection because the exclusivity cuts are equivalent to very tight isolation cuts. The efficiency for triggering, reconstructing, and identifying a signal event is $\varepsilon_{\gamma\gamma} = 0.57 \pm 0.07$.

B. Cosmic Rejection

Cosmic rays are rejected from the data sample using the timing of the electromagnetic calorimeter cluster (EMTime). The EMTime of each photon candidate is required to be less than 10 ns, and the difference between the EMTime of the two photon candidates is required to be less than 10 ns. The efficiency for this cut is $\varepsilon_{cosmic} = 0.93 \pm 0.03$.

C. Exclusivity

In order to determine that there was no other activity in the CDF detector each calorimeter region was analyzed to determine its noise thresholds. Noise thresholds were chosen in 18 different regions of the calorimeter. A calorimeter tower that is not part of an photon cluster that is above its noise threshold is called an *additional* tower. Only events with zero additional towers are included in the signal sample. The 3 events that pass into the candidate sample are discussed in Section IV.

The efficiency of the exclusivity cuts, ε_{exc}, must be calculated as a function of the bunch luminosity[11]. The ε_{exc} can be defined as the probability that the CDF detector is in a state that is capable of observing an exclusive interaction, meaning that there can be no second $p\bar{p}$ interaction in the crossing. This means that the detector must pass all of the exclusivity cuts. The value of ε_{exc} as a function of bunch luminosity is calculated from zerobias data (triggered solely on the bunch crossing time) as the number of zerobias events that pass the exclusivity cuts divided by the total number of zerobias events. Figure 2 shows ε_{exc} (points with scale on right) as well as the weighted bunch luminosity distribution of the data sample. From this plot, the overall ε_{exc} for the data sample is determined as the integral of the filled histogram divided by the integral of the empty (line) histogram to be $\varepsilon_{exc} = 0.0856$.

D. Conversions

A consequence of the exclusivity cuts is that photon that converts to an e^+e^- pair could be excluded from the signal sample. This inefficiency is accounted for by passing ExHuME generated signal events through the exclusivity cuts. The efficiency works out to be $\varepsilon_{fsr} = 0.87 \pm 0.09$.

IV. SIGNAL SAMPLE

The signal sample of 3 events is compared to the ExHuME Monte Carlo in Figures 3 to 7. They show that there is agreement between the data and MC within the statistics of the sample. Event display pictures of the 3 events are shown in Figures 8 to 10.

V. BACKGROUNDS

A. 'Jet' Fake Background

The jet fake background is the probability that some exclusive hadronic state, like $\pi^0\pi^0$, fakes the exclusive photon signal when both hadrons are reconstructed in the detector as photons. By examining the probability that a calorimeter cluster passes the photon cuts and then determining an upper limit on the number of events with two exclusive calorimeter clusters (no photon cuts), the upper limit on the jet fake background is determined to be 0.1. Therefore the jet fake background is $0.0^{+0.1}_{-0.0}$.

B. Cosmic Background

By examining the distribution of EM Timing in cosmic ray events, the probability that a candidate event comes from a cosmic ray is 2.3×10^{-4}. This corresponds to a negligible background in the 3 event candidate sample.

C. Exclusivity Background

The exclusivity background accounts for non-exclusive events where some particle(s) passed through the cracks of the calorimeter coverage or below the noise thresholds, causing them to appear exclusive. The number of additional clusters is plotted for the two-photon sample after requiring that there be no tracks in the event (other than tracks consistent with a conversion). An additional cluster is defined as a cluster of additional towers, where an additional tower is defined as a tower above the exclusivity threshold that is not part of a photon cluster.

Figure 11 shows that there are the three exclusive candidate events in the zero cluster bin, and only one potential background event in the 13 cluster bin (far from the signal region). The requirement that there be no tracks (other than the conversion tracks) eliminates virtually all of the background. The background is estimated by taking the average number of events between bins 1 and 20. This produces a background of 0.05 events. Since this is a very conservative estimate, the background used for the cross section calculation will be $0.00^{+0.05}_{-0.00}$

D. Dissociation Background

The dissociation background for $\gamma\gamma$ events is expected to be very low because there are few excitation states available to the proton in the exclusive QCD mechanism. Almost all N and Δ resonances are available for excitation in the QED mediated exclusive processes, while only $N(1440)$, $N(1710)$, and $N(2100)$ are available to the QCD-mediated exclusive processes due to the spin selection rule [9]. Using the DPMJET MC [10] the fraction of dissociation background events in Pomeron exchange events was determined to be is 1.5% This is similar to the Durham group estimation that there should be on the order of 0.1% dissociation background. After taking into account the relative cross sections for single diffraction, double diffraction, and exclusive diffraction, the DPMJET estimation corresponds to 0.05 events in the 3 event candidate sample.

Background	Value
Jet Fakes	$0.0^{+0.1}_{-0.0}$ (sys)
Cosmic	negligible
Exclusive	$0.00^{+0.05}_{-0.00}$ (sys)
Dissociation	$0.0^{+0.05}_{-0.00}$ (sys)
Total	$0.0^{+0.2}_{-0.0}$ (sys)

TABLE I: Summary of backgrounds

Quantity	Value	Uncertainty
N_{sig}	3	$^{+2.9}_{-0.9}$ (stat)
N_{bkgd}	0.0	$^{+0.2}_{-0.0}$ (sys)
$\mathscr{L}$	532	32 (sys)
ε_{exc}	0.0856	n/a
ε_{cos}	0.93	0.03 (sys)
ε_{conv}	0.87	0.09 (sys)
$\varepsilon^{\dagger}_{\gamma\gamma}$	0.57	0.07 (sys)

TABLE II: Summary of numbers put into the cross section calculation.

E. Indistinguishable Physics Processes

There are physics process other than $gg \to \gamma\gamma$ that can produce an exclusive $\gamma\gamma$ final state. The Durham group calculates that the contribution from quark exchange diagrams is $< 5\%$ and from $\gamma\gamma \to \gamma\gamma$ is $< 1\%$ [5]. These processes are not experimental backgrounds, and thus, will not be treated as such.

F. Background Summary

The sum of all background estimates discussed above is $0.0^{+0.2}_{-0.0}$. A summary of the backgrounds is shown in Table I.

VI. CONCLUSION

The cross section for exclusive $\gamma\gamma$ ($E_T > 5$ GeV, $|\eta| < 1$) is evaluated using the values in Table II to be:

$$\sigma^{E_t>5\ GeV,|\eta|<1}_{exc,\gamma\gamma} = \frac{N_{sig} - N_{bkgd}}{\varepsilon_{conv}\varepsilon_{cos}\varepsilon_{\gamma\gamma}\varepsilon_{exc}\mathscr{L}} = 0.14\ ^{+0.14}_{-0.03}\ (stat)\ \pm 0.03\ (sys)\ pb \tag{1}$$

This is consistent with the theoretical cross section calculation from the Durham group which is 0.04 pb with an uncertainty factor of 3 to 5. The probability that a background of 0.2 fluctuates to 3 or more events is 1.1×10^{-3}. This corresponds to 3.3σ evidence for QCD-mediated exclusive $\gamma\gamma$ production.

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[9] J.Forshaw, Diffractive Higgs Production: Theory, hep-ph/0508274 (2005).
[10] R.Engel, et al., hep-ph/0012252
[11] Bunch luminosity is the instantaneous luminosity of the bunch crossing

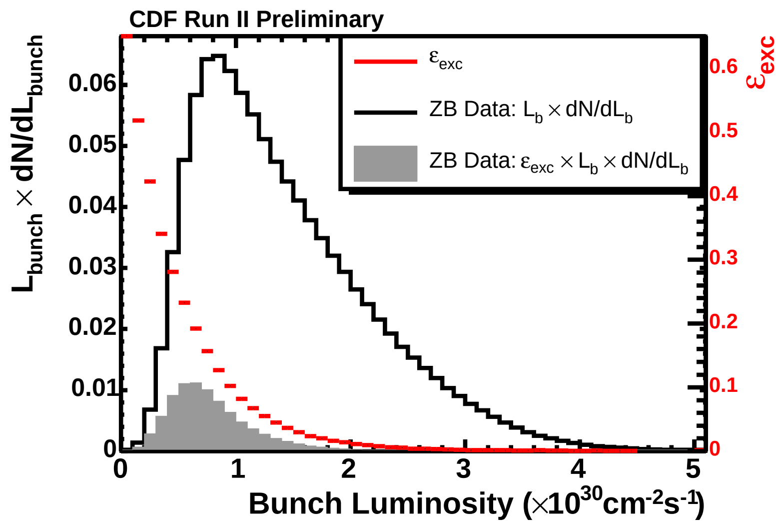

FIG. 2: Bunch luminosity distribution for all zerobias data (open histogram with scale on left), ε_{exc} (points with scale on right), and weighted bunch luminosity (filled histogram with scale on left).

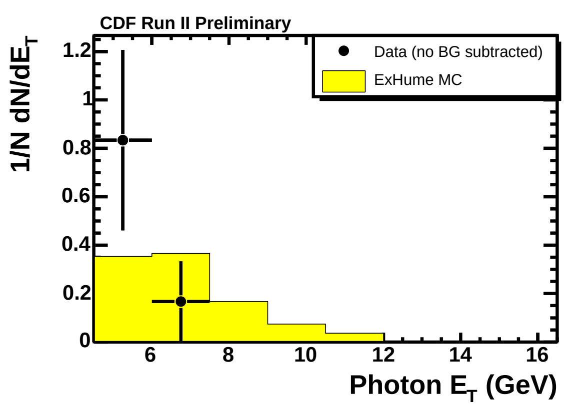

FIG. 3: E$_T$ of photons in signal sample (points) compared to Exhume MC (line)

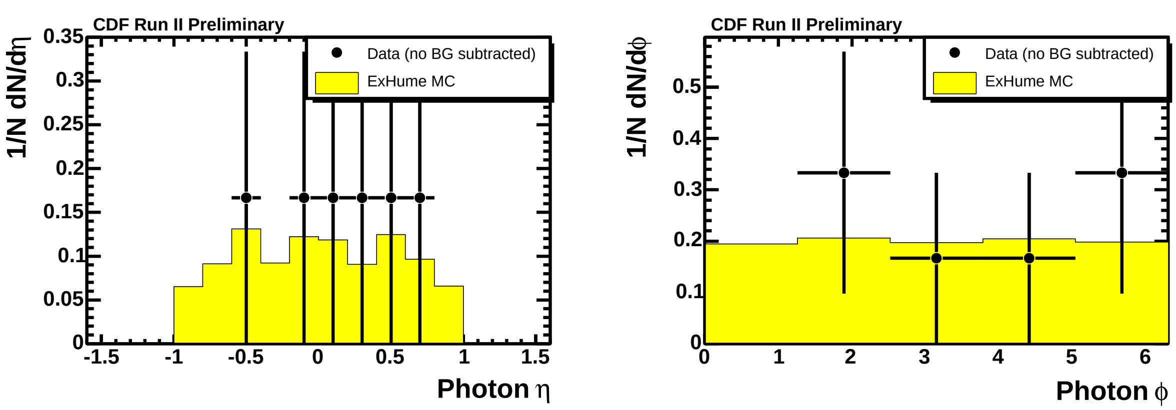

FIG. 4: eta (left) and phi (right) of photons in signal sample (points) compared to Exhume MC (line)

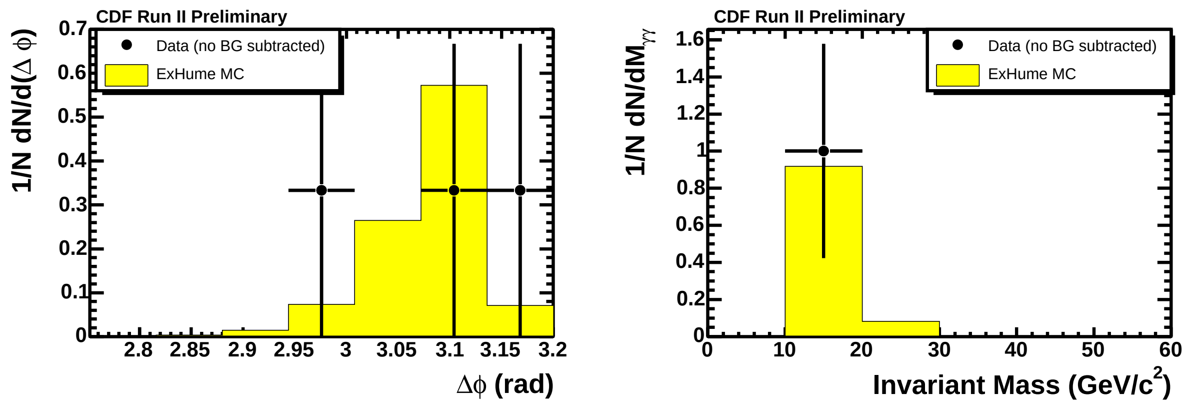

FIG. 5: Delta ϕ (left) and invariant mass (right) of photon pairs in signal sample (points) compared to Exhume MC (line)

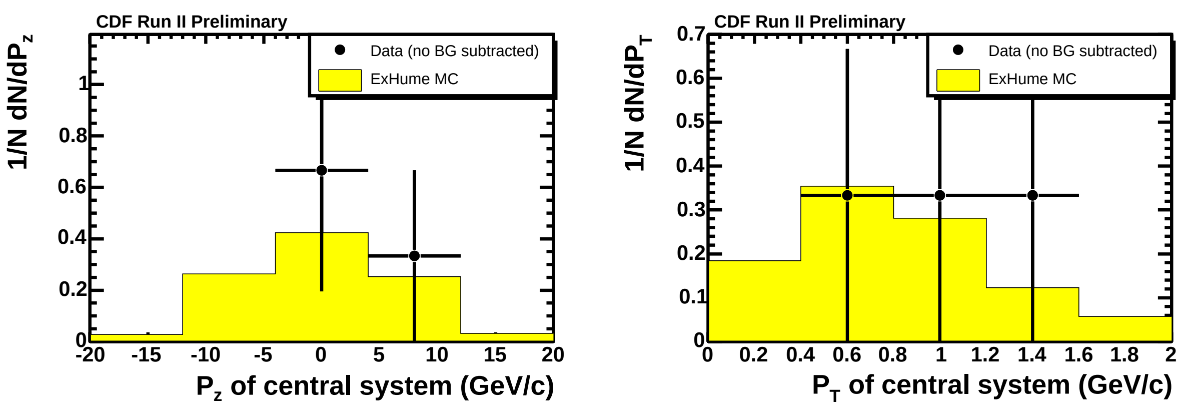

FIG. 6: p_z and p_t of photon pairs in signal sample (points) compared to Exhume MC (line)

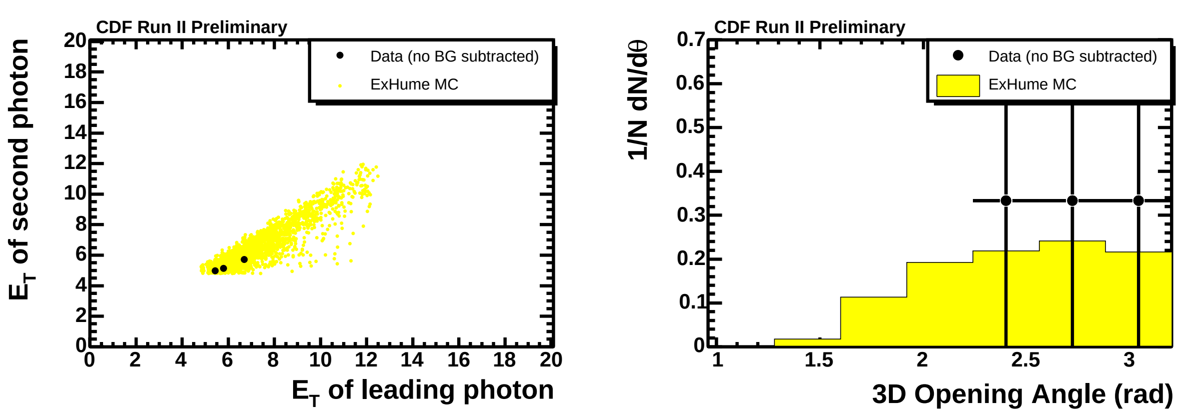

FIG. 7: E_T vs E_T (left) and 3d opening angle of photon pairs in signal sample (points) compared to Exhume MC (line)

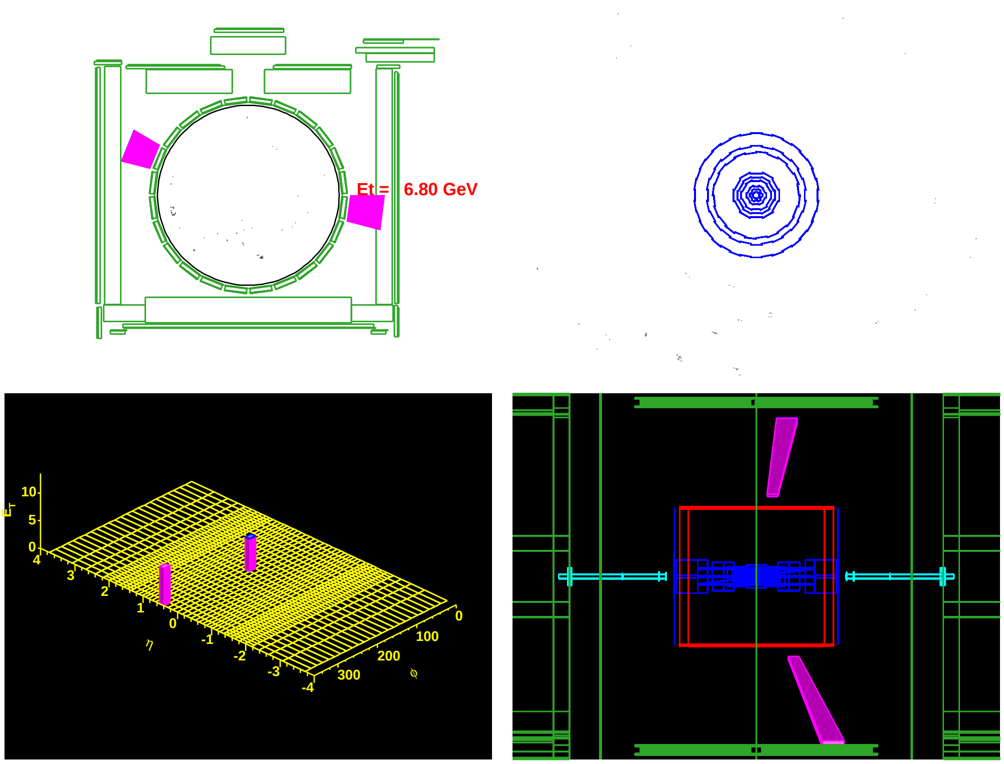

FIG. 8: Event display of run 191089 event 127812.

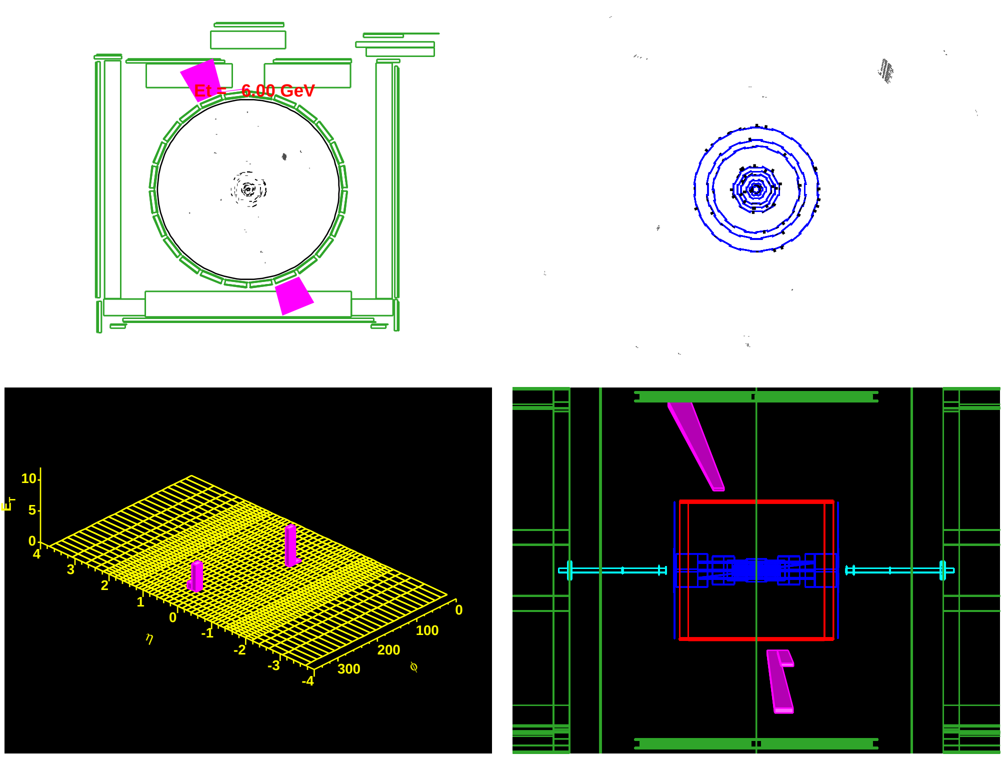

FIG. 9: Event display of run 199189 event 6276945.

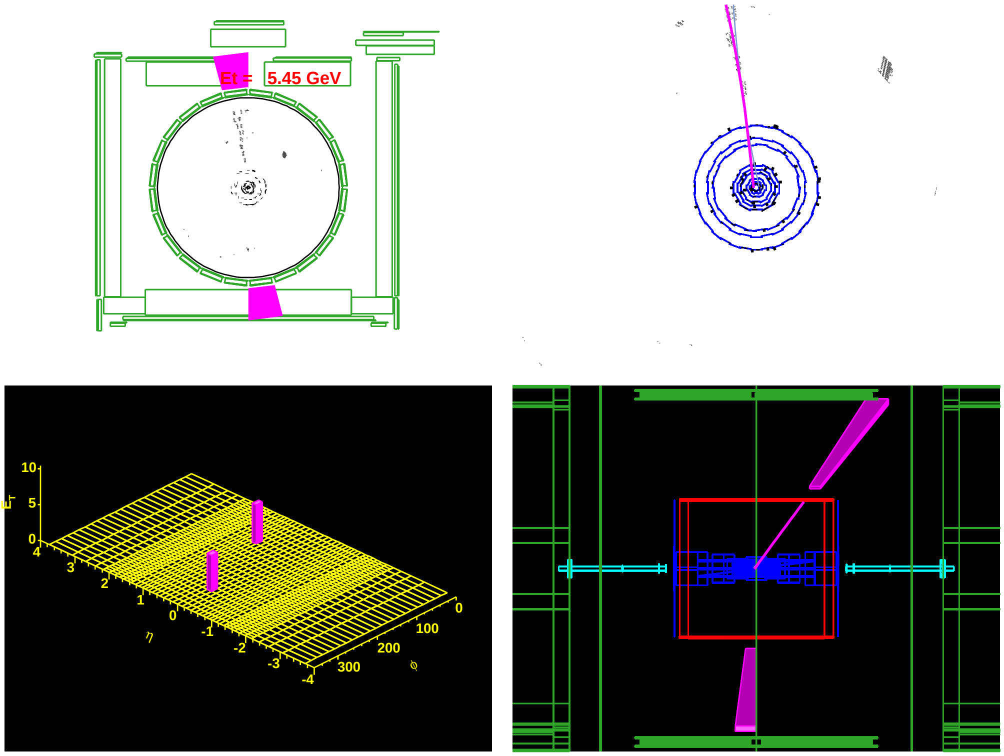

FIG. 10: Event display of run 200284 event 346775 (note the conversion).

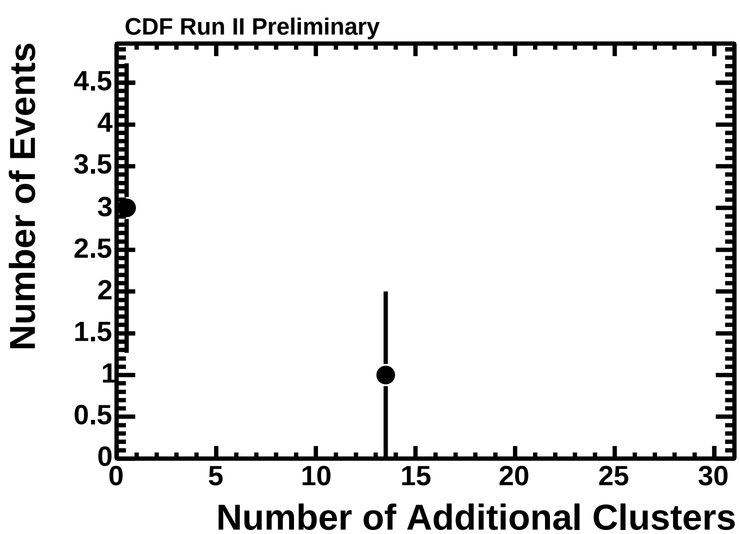

FIG. 11: Number of associated towers in two-candidate events after tracking cut is applied.